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A PROBLEM OF METALURGY AND PRODUCTION OF SHAPE COMPLEX Mg CASTINGS

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ABSTRACT: The paper shows a primary research made at the CTU in Prague with the view of starting a casting of Mg alloys in Czech Republic. Trend to reduce weight of construction parts for automotive industry and information technology leads to increasing light alloys use. Research on Faculty of Mechanical Engineering CTU in Prague in cooperation with other universities and plants is based on study of mechanical and technological properties of magnesium alloys. The basis of the project was a research; the second step was a buying of a melting furnace. Some numeric simulations were made. The future of this project is to manage the metallurgy with different protective gasses, to cast samples for mechanical properties testing, to cast in different mold materials and to build the ground for high-pressure die-casting.

KEY WORDS: Magnesium alloys, metallurgy of Mg alloys, casting, protective gas.

1 INTRODUCTION

Key advantages of magnesium and its alloys used in the casting process are as follows:

- Low density, which means savings in casting weight or more robust construction
- Big performance/density ratio, which means good mechanical properties with low weight
- High fluidity, which means better mold filling and good castability
- Low volumetric specific heat, which means quick solidification

There are some disadvantages:

- High flammability and explosive behavior, which means special requirements for melting and casting like protective environment, special crucibles, additives in mold material, higher demands for casters skills, etc.
- The fast cooling and solidification can cause incomplete mold filling in case of wrong gating system design
- Relatively high percentage of volume changes, which means (in combination with fast cooling rate) a low metal utilization and high risk of shrinkage when wrong feeding is designed
- Worse corrosion properties

Above-mentioned information should be taken into account before starting the casting production.

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2 METALLURGY

2.1. ALLOY SPECIFICATIONS

The current commercial magnesium alloys for casting contain **aluminum** as the main alloying element. Aluminum improves the mechanical strength, corrosion properties and castability. Ductility and fracture toughness are gradually reduced with increasing aluminum content. This has led to the introduction of a series of alloys with reduced aluminum contents, the AM-series, which are used extensively automotive safety related components.

Zinc is added to the AZ-series. In the most common casting alloy AZ91is the level of zinc around 0,7 wt%, resulting in a minor improvement of strength and corrosion properties.

Manganese is added to control the iron content of the alloys. The level of manganese additions vary from one alloy to the other, depending upon the mutual solubilities of iron and manganese in the presence of other alloying elements. A basic requirement for the high purity alloys is that the iron content is limited to a maximum of 0,005 wt%. Other impurities like nickel and copper must also be strictly controlled.

Efforts to improve the elevate temperature creep properties have resulted in the introduction of alloys containing silicon or **rare earth** (RE) elements. These alloying elements form intermetalic constituents that stabilize the grain boundaries. In these alloys, aluminum has to be kept at relatively low levels. **Beryllium** is added to levels in range 5 – 15ppm to reduce the oxidation rate in the molten condition.

Magnesium alloys may be divided into two groups: the san-casting alloys that utilize the beneficial effect of the extremely fine grain-structure caused by small additions of **zirconium**, and the die-casting alloys in which aluminum is the principal alloying element. The composition and mechanical properties of these alloys are listed in Tab. 1. and 2 [1].

The workhorse is AZ91, which shows excellent castability and high strength combined with moderate ductility. It should always be considered the first choice unless it is ruled out by specific property requirements. For applications requiring greater fracture toughness and hence the ability to absorb energy without failure, the AM-series with a lower aluminum content has been developed. AM60 and AM50 have found widespread application in safety parts like automotive instrument panel supports, steering wheel armatures and seat parts (HPDC castings). To some extent, the castability is diminished as the aluminum content is reduced, and so the alloy with the highest aluminum content that will have the required properties should be chosen.

In the case of applications involving long-term exposure of stressed components at temperatures exceeding 120°C, attention should be paid to the creep properties of the alloy. The AS- and AE series have been developed for use in such applications and show good creep properties up to 150°C. These alloys are based on the addition of either **silicon** or RE elements, which promote the formation of finely dispersed particles at the grain boundaries. These alloys also have good mechanical properties at room temperature.

2.2. MELTING AND HANDLING

Magnesium alloys are supplied to die casters in the form of ingots. It is necessary to dry them and preheat them to at least 150°C before they are fed into the melt, to prevent moisture from entering the liquid metal. Magnesium can be melted in furnaces heated by electrical resistance, induction, oil or gas. Gas fired furnaces have commonly been used in the USA because of the relatively low cost of gas. However, drawbacks such as increased crucible wear due to scaling from hot spots, and high humidity due to the formation of moisture have led to electrical resistance furnaces being used increasingly. In Europe, resistance furnaces continue to dominate. Our school foundry shop is equipped also with resistance furnaces as shown in Fig. 1. The furnace was made by company LAC, s.r.o. especially for our needs, it is a prototype. It has special equipment for feeding the protective gases etc.

Tab. 1: Chemical compositions (specifications for die-casting parts)

Alloy	Al	Mn	Zn max	Si max	Cu max	Ni max	Fe max	Others, max for each
AZ91D[1)]	8,3-9,7	0,15-0,5	0,35-1,0	0,1	0,03	0,002	0,005	0,02
AM60B[1)]	5,5-6,5	0,24-0,6	0,22	0,1	0,01	0,002	0,005	0,02
AM50A[1)]	4,4-5,4	0,26-0,6	0,22	0,1	0,01	0,002	0,004	0,02
AM20[2)]	1,6-2,6	min.0,1	0,2	0,1	0,01	0,002	0,005	0,02
AS41B[1)]	3,5-5,0	0,35-0,7	0,12	0,5-1,5	0,02	0,002	0,0035	0,02
AS21[2)]	1,8-2,6	min.0,1	0,2	0,7-1,2	0,01	0,002	0,005	0,02
AE42[2)3)]	3,5-4,5	min.0,1	0,2	0,1	0,02	0,002	0,005	0,02

1) ASTM B94-94 (in CR it defines ČSN 42 49xx)
2) Recommended values
3) RE cerium, lanthanum, praseodymium, neodymium: 2 – 3%

Tab. 2: Mechanical properties at room temperature

Alloy	Ultimate tensile strength [MPa]	Tensile yield strength [MPa]	Fracture elongation [%]
AZ91	250	160	7
AM60	240	130	13
AM50	230	125	15
AM20	210	90	20
AS41	240	140	15
AS21	220	120	13
AE42	230	145	11

With relatively effective designs the energy consumption when magnesium alloys are melted (including preheating) is approximately 400 to 500 kWh per 1000 kg melted metal, compared to theoretical minimum 310 kWh. Melting ranges and casting temperatures are shown in Fig. 2 [1].

As widely known, it is necessary to protect the melt surface. The routine especially in gravity casting shops is to sprinkle the surface with protective flux, which is fused salt mixture ($MgCl_2$, NaCl, CaF_2 [2]). The trend is to change to protective gas mixtures, which are usually based on SF_6, SO_2 etc. The advantages of fluxless melting include reduction of sludge formation and thus less metal loss, the absence of flux contamination in castings, and an improved atmosphere in the casting shop. The other thing is the shape of crucible: for flux is better to have deep crucible with small diameter to have as small melt surface as possible, for protective gas can the crucible have common shape.

Because of ecological aspects of using sulphur, new protective mixtures are developed and tested, what is also a goal of our research project. We would like to test argon, CO_2, CO_2snow, which also cools the surface and pushes the oxygen away. The other studies speak about BF_3 and stuffs containing fluorine or fluorine ketons.

For gravity casting is recommended to add modification reagents. In our foundry lab we will use tablets Spefinal for modification and for degassing.

Fig. 1: Melting resistance furnace in our foundry shop

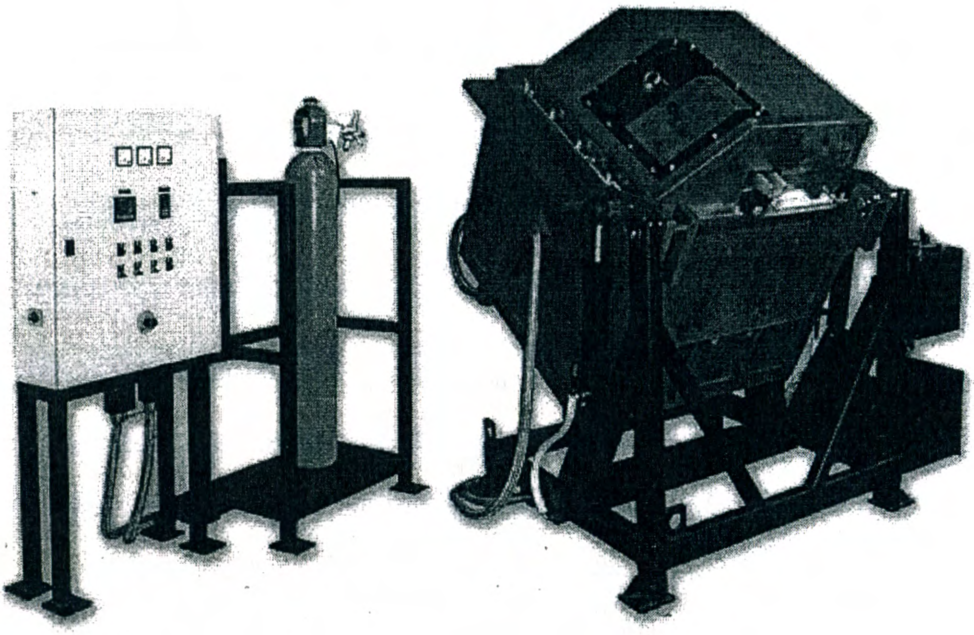
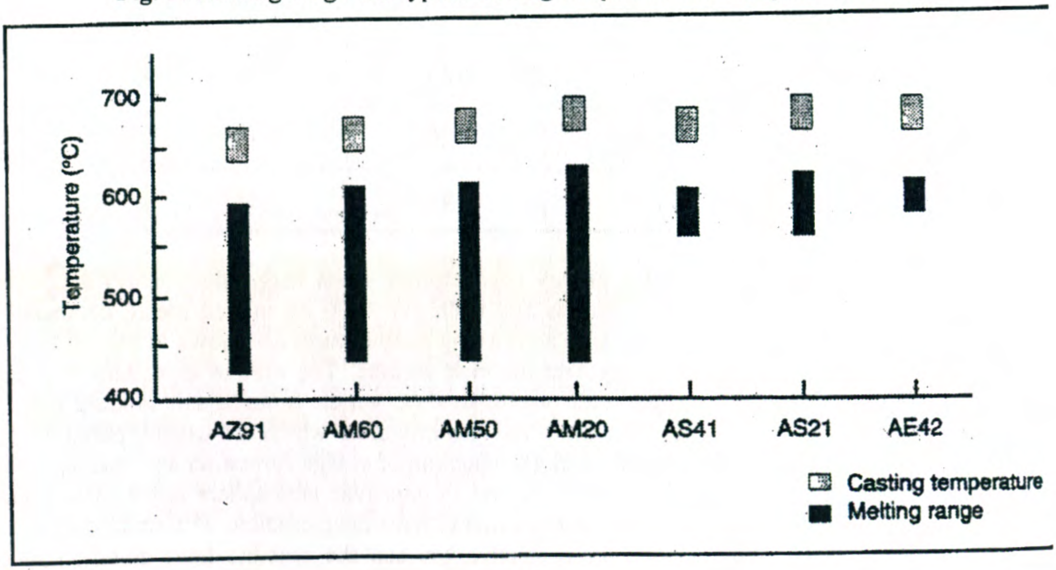


Fig. 2: Melting range and typical casting temperatures of magnesium alloys



2.3. TRANSPORTATION AND POURING

In HPDC foundries is the metal transported by pumping in the heated steel tube directly to the holding furnace, which has a dosing pump. The pumps may be gas pressure, piston, centrifugal, electromagnetic or gravity types. The tubes are preheated either by electrical resistance windings or by resistance in the tube itself.

In gravity foundries is the transport depending on the automatization level. The routine is to transfer the molten metal in the melting crucible to minimize the moving of the liquid. Our furnace is tilting and we suppose to pour directly into the mold.

When pouring, the metal flow should be protected as well. The routine is to sprinkle the flow with sulphur by the textile bag directly. In our foundry shop when pouring directly from the furnace, the protective gas is supposed to follow the flow. For pouring into open molds (cups for thermal analyses, ingots from the rest of metal, etc.) we plan to use a jet feeding the protective gas directly on the flow.

For safe filling of the mold is necessary to add some inhibitors into molding sands. It should not contain any organic stuffs, which could cause gas bubbles creation. The sand should have maximal permeability and the minimal moisture content. The binder should have as small gasses creation as possible and the core sand should get dry as fast as possible at low temperatures. Basically, all common types of molding sands can be used: dry green sand especially chemically modified; graphite sands with high heat conductivity; green sand with sulphure addition or with boratic acid or ammonium fluoroborate; sand with sodium silicate hardened by CO_2 with sulphure or fluoride addition (especially for cores); and calcium sulfate with ammonium fluoroborate. Last years are widely used furan sands. In some cases the mold cavity can be filled by SO_2 gas before pouring of the molten metal into a mold.

3 EXPERIMENTS

3.1. BASIC RESEARCH

For a good knowledge about magnesium, its alloys and behavior it was necessary to make a basic research, to make some testing and simulations. Within some projects and research programs we collected many of information about magnesium and all known techniques of treatment of magnesium alloys. One of tests, which were made in our lab by our colleagues [3, 4], was the tensile strength test of AZ91 casting as shown in Fig. 3 and other tests of cast structure as shown in Fig. 4. The testing confirmed table values from literature.

3.2. NUMERICAL SIMULATIONS

For better knowing of the castability we made some numerical simulations of AZ91 alloy castings, which are shown in Fig. 5. For this simulations was used the simulation software Qucikcast. Now we are working on simulations of difficult shape casting as shown in Fig. 6. In cooperation with foundry BEZ Motory, a.s., which is the only one foundry having a Mg castings production running, we try to find the best gating system and its position as well as the feeding system for this casting. For this simulations is used the simulation software ProCast. Within other research project we have made some simulation of HPDC process, where we set different mold and metal temperatures. For this simulations was used the simulation software Nova Flow&Solid.

Fig. 3: The tensile strength test

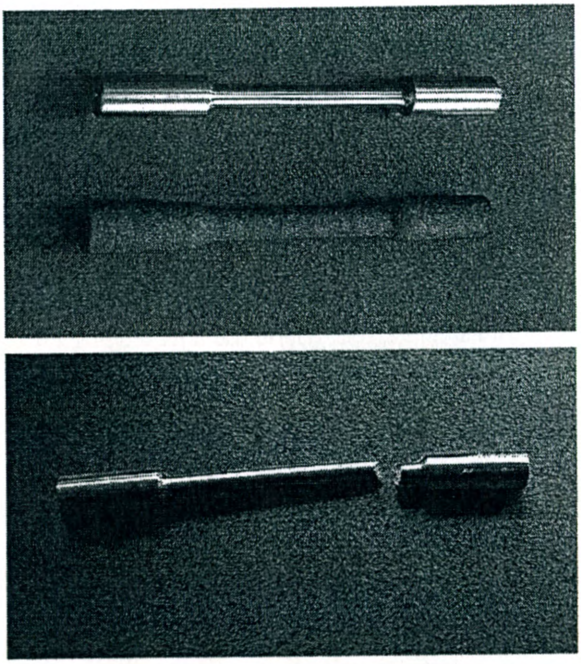


Fig. 4: Compression strength test

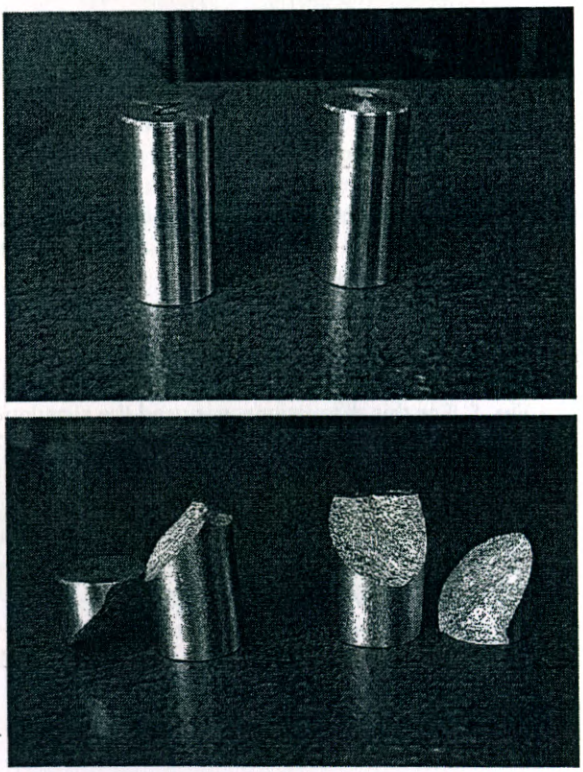


Fig. 5: Casting after machining, which was simulated (filling and solidification)

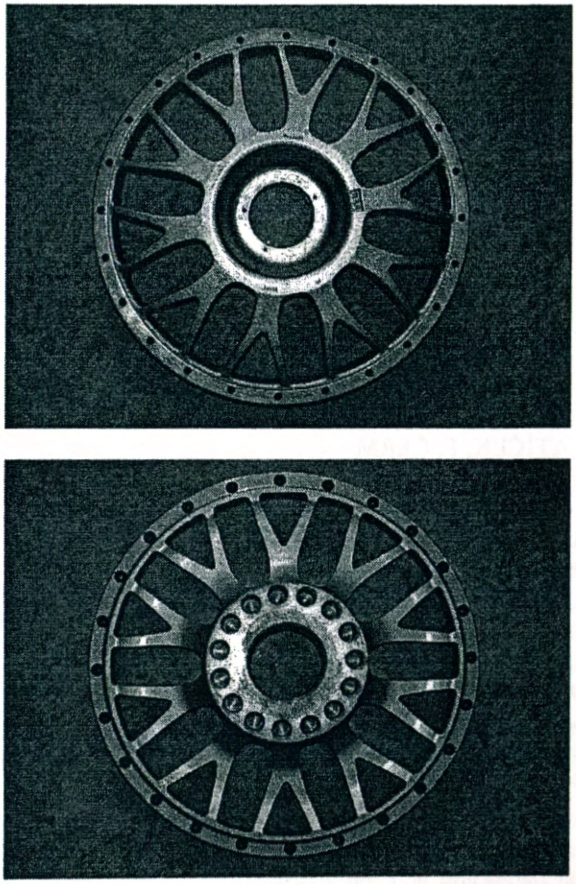
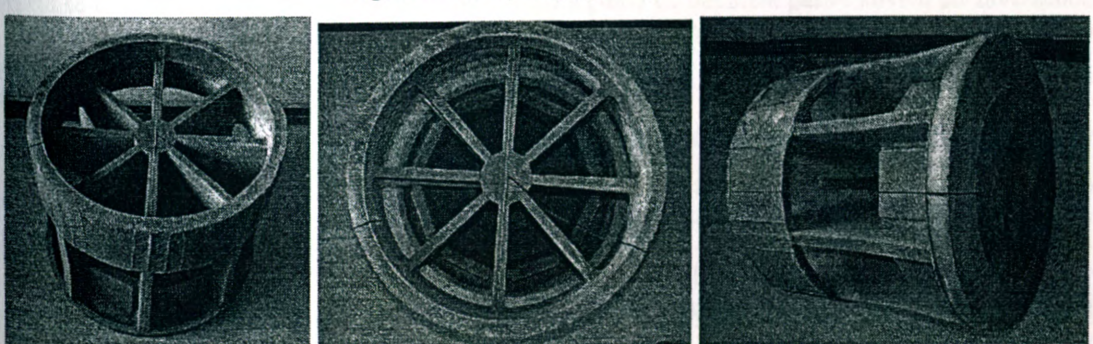


Fig. 6: Difficult shape gravity casting



3.3. MELTING AND CASTING

On this part of our paper we have to apologize, because when we had applied for this conference, we supposed to have the melting place ready and have some meltages done. Because of some problems with installation of the furnace, the melting place is still not working so we cannot introduce any results.

4 GOALS FOR A FUTURE

For a future we want finally to fully run the melting place for Mg alloys in our lab foundry, we would like to keep cooperation with Mg foundries and with foundries, which want to start the casting of Mg alloys. We would like to try different casting methods e.g. investment casting, different molding sand types, gravity die-casting etc. with different alloy types as well as testing of different protective gases on the melted metal surface. As mentioned in abstract, our big goal is to build the ground for high-pressure die-casting in our country.

5 REFERENCES

[1] COMPOSITE AUTHORS: Die Casting Handbook. NADCA, Second Edition, 2001.

[2] JUŘIČKA, I., MAISNAR, J. : Specifické podmínky tavení a lití hořčíkových slitin. Slévárenství, 2004, roč. LII, č. 2-3, s. 66-70.

[3] ČERMÁK, J.; HAWELKA, M.; TATÍČEK, F.: Současné trendy ve zpracování hořčíkových slitin tvářením. MM Průmyslové spektrum, 2005, č. 10, s.59-62. ISSN 1212-2572.

[4] HAWELKA, M.; TATÍČEK, F; ČERMÁK, J.: Forming of magnesium alloys – feasibility study. In. CO-MAT-TECH 2005 – 13. mezinárodní vědecká konference, Trnava 20.-21. října 2005. Ed. Květoslava Rešetová at. al. Bratislava, 2005. p. 52. ISBN 80-227-2286-3.

[5] HERMAN, A., STUNOVÁ, B.: Výhody použití Mg slitin v porovnání s ostatními konstrukčními materiály. 1. díl. MM Spektrum – 10/2005 – str. 94 – 95.

[6] HERMAN, A., STUNOVÁ, B.: Výhody použití Mg slitin v porovnání s ostatními konstrukčními materiály, 2. díl. MM spektrum – 11/2005 str. 48 – 49.

[7] HERMAN, A., STUNOVÁ, B.: Výhody použití Mg slitin v porovnání s ostatními konstrukčními materiály. 3. díl. MM Spektrum – 12/2005 str. 72-73.

[8] HERMAN, A:, STUNOVÁ, B.: Realization of melting workplace for Mg alloys at CTU in Prague. Konference CO-MAT-TECH, Trnava, 20 - 21. 10. 2005, ISBN 80-227-2286-3, strana abstrakt – 54, plný text CD – ROM, ISBN 80-7194-803-9, 2005, str. 79 – 82.